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A Computer Control Interface to Operate Turntables in the Test Section of a Wind Tunnel

S.A. Kent

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Aeronautical and Maritime Research Laboratory

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ABSTRACT

The Low Speed Wind Tunnel at the Aeronautical and Maritime Research Laboratory (AMRL) has, as part of its system, two interchangeable chambers, known as "test sections" where models to be tested are mounted. One of the requirements of a recent upgrade to the Low Speed Wind Tunnel control and data acquisition system was the ability to precisely position the turntables using computer control. This report describes the electronic hardware and software developed to enable computer control of the turntables by wind tunnel personnel.

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Executive Summary

The Low Speed Wind Tunnel at the Aeronautical and Maritime Research Laboratory (AMRL) has, as part of its system, two interchangeable chambers, known as "test sections" where models to be tested are mounted. Each test section measures 2.7 m x 2.1 m and has two turntables that are 1.58 m in diameter, one in the floor and the other in the ceiling. The turntables are driven by electric motors and can be rotated through 360° to enable the model to be yawed with respect (or relative) to the direction of the airstream. For the purposes of testing, models can be mounted directly on the lower turntable, or connected between the upper and lower turntables, or on the upper turntable.

The turntables are microprocessor controlled using a Model Attitude Module that uses solid state relays to interface with the 415 V three-phase electric motors. Position feedback is provided by single-turn resolvers, with 0.1° accuracy. The option is available to simultaneously drive up to four test section turntables plus another turntable on an under-section mechanical load-measuring balance. The balance turntable must be driven synchronously with the lower turntable and, if required, with the upper turntable as well. The signals from the resolvers are fed to encoders that continuously convert shaft position data into parallel binary data for input to the microprocessor via parallel interface cards.

The Model Attitude Module is capable of driving up to five turntables separately, or in unison, while reading the resolvers associated with each turntable, which allows precise positioning control of all turntables. The module also provides manual control of turntable movement and software limits to restrict turntable rotation. Status information is sent to a master computer to determine when the turntables have reached their desired position. Additional status information relating to resolver response limits, manual control and relay power is also provided.

Authors

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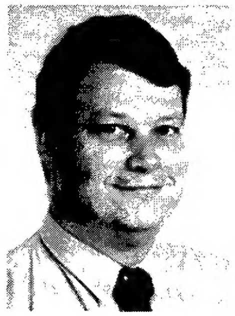

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1. Introduction

The Low Speed Wind Tunnel at Aeronautical and Maritime Research Laboratory (AMRL) has, as part of its system, two interchangeable chambers, known as "test sections" where models to be tested are mounted. Each test section measures 2.7 m x 2.1 m and has two turntables that are 1.58 m in diameter, one in the floor and the other in the ceiling. The turntables are driven by electric motors and can be rotated through 360° to enable the model to be yawed with respect (or relative) to the direction of the airstream. For the purposes of testing, models can be mounted directly on the lower turntable, or connected between the upper and lower turntables, or on the upper turntable.

One of the requirements of a recent upgrade to the Low Speed Wind Tunnel control and data acquisition system was the ability to precisely position the turntables using computer control. This was achieved with the construction of the Model Attitude Module (Figure 1, Figure 2), which is mounted in the main control and instrumentation rack in the Low Speed Wind Tunnel control room.

The turntables are microprocessor controlled, using solid state relays to interface with the 415 V three-phase electric motors, while position feedback is provided by a single-turn induction resolver. Provision is made to simultaneously drive four test section turntables plus an under-section mechanical load-measuring balance turntable. The balance turntable must be driven synchronously with the lower turntable and, if required, the upper turntable as well. The Model Attitude Module is interfaced with an interactive computer program [Ref. 1] developed by wind tunnel personnel to enable the turntables to be controlled via a master computer (DEC MicroVAX II model 630QY-D2).

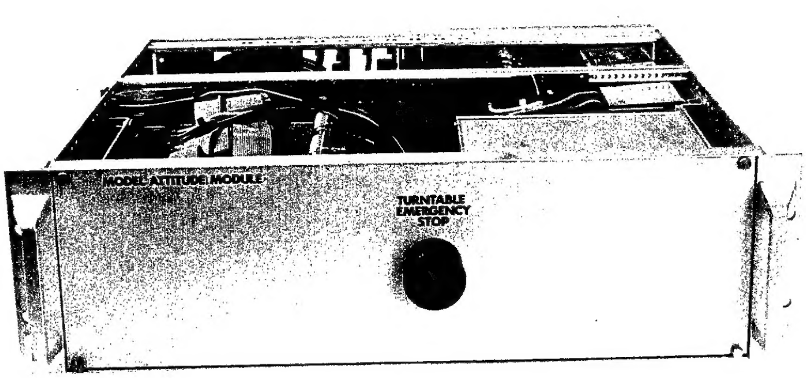

Figure 1: Model Attitude Module - Front View

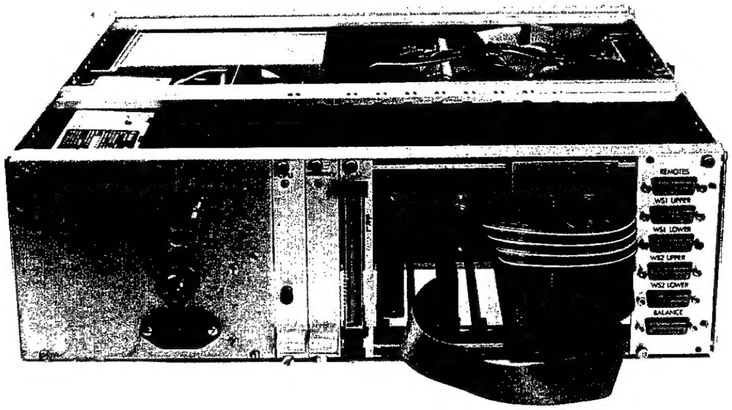

Figure 2: Model Attitude Module - Rear View

2. System Description

2.1 Model Attitude Module Electronics

The Model Attitude Module has a standard 19 inch rack-mountable single height chassis. All plug-in cards are accessed from the rear of the module. The microprocessor backplane contains 13 slots and is VMEbus [Ref. 2] compatible. All cards are constructed to Eurocard standards and the module hardware is built from standard VMEbus components. A block diagram is shown in Appendix A, Figure A1.

The module contains the following hardware:

- CPU card with dedicated Motorola MC68000 microprocessor.
- Memory card with two 2764 EPROMs and four 6116 RAM memory chips.
- Bi-directional Parallel Interface (BPI) card which interfaces the Model Attitude Module with a master computer.
- Relay drive card for computer control of turntables, and interfacing of manual control units (Section 3).
- Resolver-encoder interface card (Appendix A, Figure A2).
- Three parallel digital input/output cards that utilise the Motorola MC68230 Parallel Interface/Timer (PI/T) chip [Ref. 3].
- Two absolute encoder modules, one comprising four encoder channels, and the other comprising one encoder channel (Section 2.2).
- Emergency Stop button (front panel) for power cut-off to relays in the event of a turntable run-away condition.

- One Gould Econoflex power supply with the following voltages:
  +5 V @ 10 A
  +12 V @ 1.5 A
  -12 V @ 1.5 A
- One AMRL designed power supply (PL 57369) with the following voltages:
  +5 V @ 10 A
  +15 V @ 1.5 A
  -15 V @ 1.5 A

2.2 Resolver and Encoder System

The transducer used to measure turntable position is a Singer ST-11E single-turn induction resolver, which is essentially a transformer with a rotary electromagnetic coupling between the primary and secondary windings. The windings are located on the stator and rotor in such a manner that the output voltage has an amplitude which is proportional to the sine or cosine of the input shaft position. The resolver produces low frequency (400 Hz range) analog signals that are transmitted through the system interface cabling (Appendix A, Figure A3) to the absolute encoder. The basic absolute encoder system is shown in Figure 3.

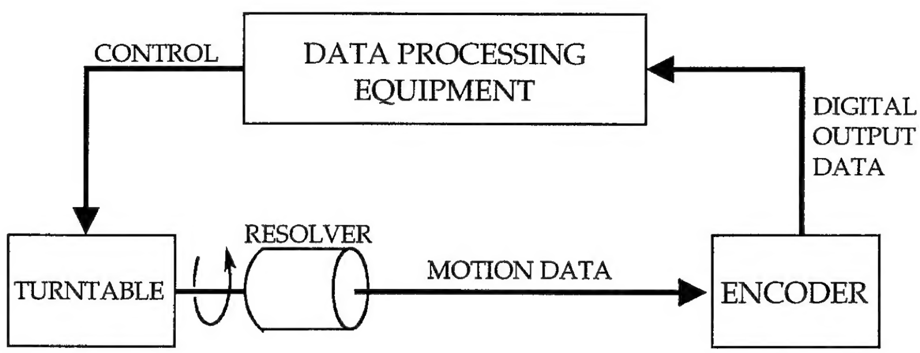

Figure 3: Basic Encoding System

The resolver is mounted on the test section housing adjacent to the turntable drive gear (Figure 4). A gearing system provides a final turn ratio between turntable and resolver of 1:1.

The encoders used in this system are manufactured by Astrosystems Inc. and comprise a four channel unit (model number EC3010-4) and a single channel unit (model number EC3010-1) [Ref. 4]. All channels have a resolution of 3600 counts per 360°, which provides an accuracy of 0.1°, and the digital output data is in binary coded decimal (BCD). The absolute encoder continuously converts shaft position data into

parallel binary data (once every 2.5 ms) which is accessed by the microprocessor via the parallel interface cards.

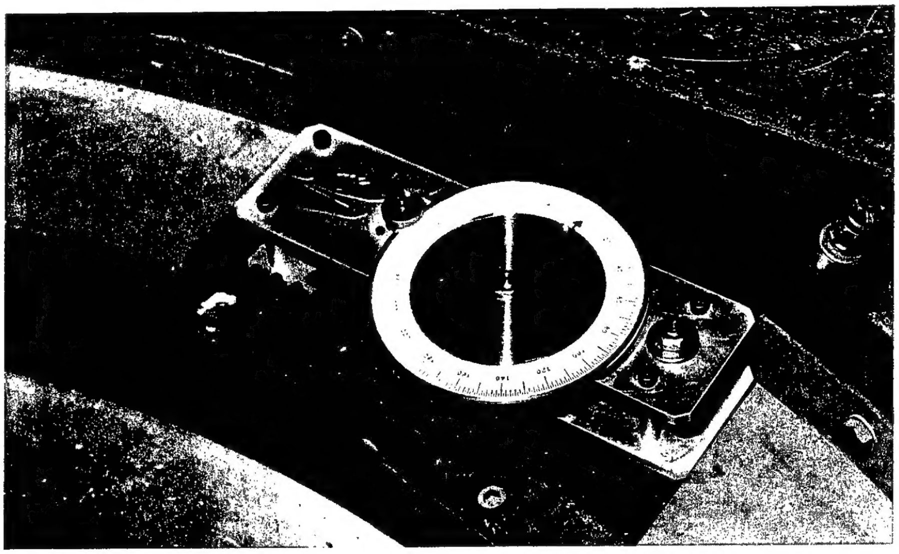

Figure 4: Resolver Mounted on Test Section

Each encoder issues a 10 μs Data Ready pulse to indicate that digital data are ready for access. The Data Ready line is connected to the H3 input of the PI/T which is monitored by the software (Section 4.3). The leading edge of the Data Ready pulse indicates that the data on the output lines have been updated. The trailing edge of the pulse indicates that the data are stable and can be accessed by the microprocessor. The 10-microsecond width of the pulse is the settling time allowed for the output data to stabilise.

2.3 Manual Control Units

There are two hand-held Manual Control Units (MCUs) (Figure 5) that allow the turntables to be positioned independently of the master computer. The cable attached to each MCU is approximately 10 m long which allows the operator to stand in the test section while positioning the turntable. Each MCU contains two momentary push-button switches to control turntable direction (port or starboard [Section 5.1]), and a three position rotary switch to select which turntables are to move (upper, lower [and balance if connected], or both). There is provision in the cabling and software for an emergency stop switch to be added to each MCU in the future, if required.

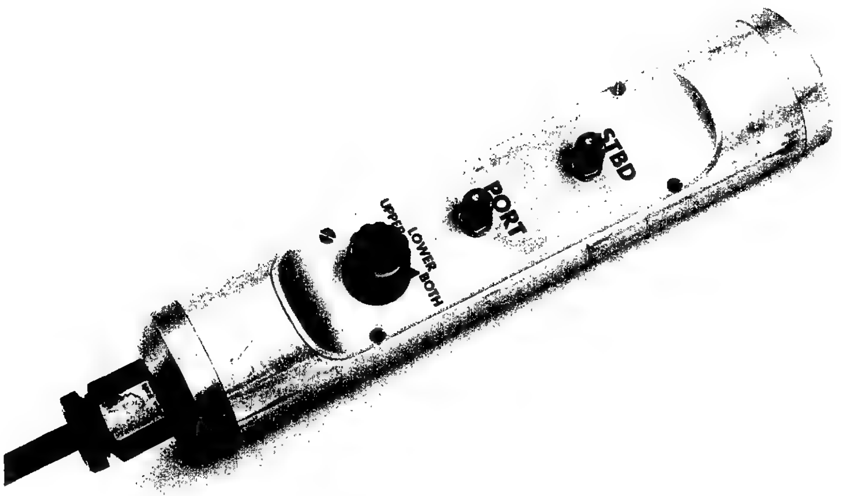

Figure 5: Manual Control Unit (MCU)

There are three locations where the MCUs can be connected:

- the north side of the test section currently placed in the wind tunnel circuit (active test section) between the control room and the wind tunnel (Figure 6),
- the south side of the active test section, and
- under the main bench in the control room.

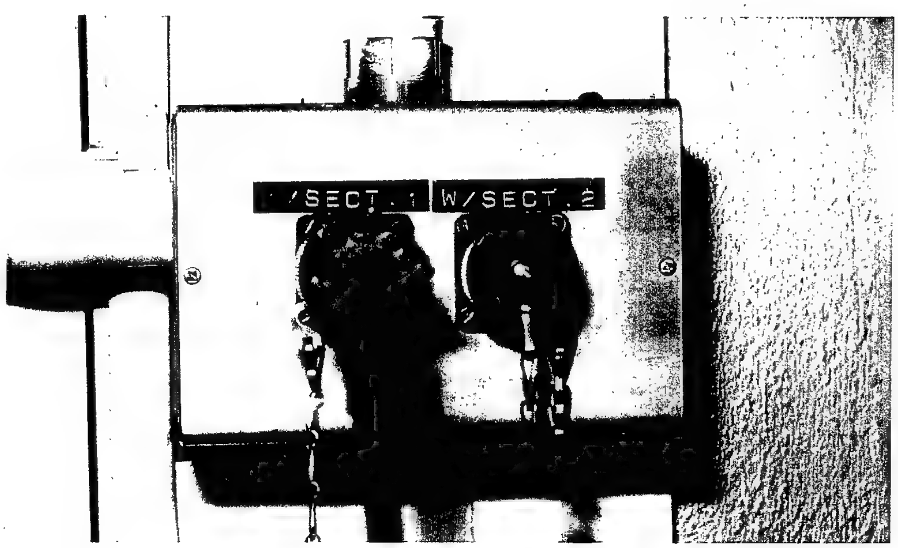

Figure 6: MCU Connection Panel (North side of active test section)

All locations have two MCU connectors, one for each test section. Each MCU is allocated to a specific test section by the use of opposite-sex connectors on the MCU cables. The cable for test section 1 is terminated with a plug, and test section 2 has a socket on its cable.

An MCU detect line is activated when the MCU is plugged in, so the software can determine when an MCU has been connected (Section 4.5) and for which test section (1 or 2). Schematic details are shown in Appendix A, Figure A4.

2.4 Active Test Section Detection

Switches are used to determine which test section is *active* (i.e. currently placed in the wind tunnel circuit). The switches are Honeywell heavy duty microswitches mounted on a beam on the North side of the wind tunnel (Figure 7), and are activated by a lever system mounted on the outside of each test section. The upper switch is activated by test section 1 and the lower switch by test section 2. These switches are sampled by the software and allow it to determine which test section is currently active. Only the active test section will be computer controlled (Section 4.6). The inactive test section can only be controlled with an MCU.

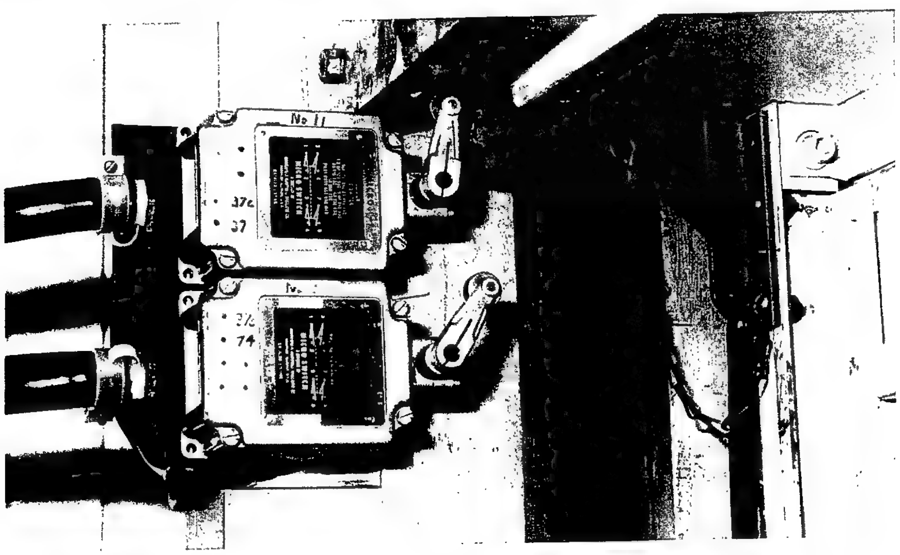

Figure 7: Test Section Detect Switches

3. Relay Drive Card

3.1 Description

The relay drive card (Figure 8) is a Eurocard standard card of 100mm x 160mm and plugs into the VMEbus backplane. This card provides the drive interface and power control to the turntable motor solid state relays, as well as interfacing with the manual control units. Schematic details and component overlay are shown in Appendix A, Figures A5 and A6.

3.2 Relay Drive Interface

Bits 0-7 of port B (PB0-PB7) and bits 0-3 of port A (PA0-PA3) in the relay PI/T are utilised to control the turntable motor solid state relays. Each PI/T output is connected to a Transistor-Transistor Logic (TTL) open-collector buffer (type 7407) driving the base of an output transistor (type 2N5088) through a current limiting resistor. A logic high (+5 V) from the PI/T turns the transistor on, and grounds the collector. If the solid state relay +5 V supply is on (Section 3.3), the solid state relay will activate the main turntable select or drive relays as required. Solid state relay connection details are shown in Appendix A, Figure A7.

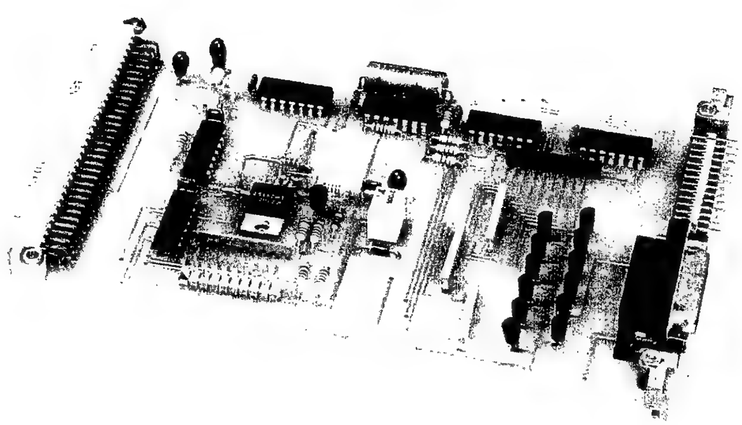

Figure 8: Relay Drive Card

3.3 Power Control

The +5 V supply to the solid state relays is software controllable by the use of a National Semiconductor voltage regulator (type LM2935). A logic high on the SWITCH pin turns the regulator on. This function is controlled by bit PA4 in the relay PI/T.

The +5 V output of the regulator is connected to the normally-open contacts of a printed circuit board mounted relay. Power to the coil of this relay is switched through a transistor, which is biased "on" under normal circumstances, closing the relay contacts. During system reset a logic low is applied to the base of the transistor for approximately two seconds, which switches it off, and the relay contacts are opened. This ensures that no voltage is applied to the solid state relays during system reset or when mains power is first applied, when unknown logic states can occur. The base of the transistor is also connected to the emergency stop switch wiring on the MCUs. This allows the provision for future emergency stop switches to turn the transistor off which will open the relay contacts.

An Emergency Stop switch mounted in the front panel of the Model Attitude Module is included in the +5 V path, which cuts power to the solid state relays if it is pressed. A voltage detection circuit is included after the Emergency Stop switch connection, which is connected to the relay PI/T through PA5. This allows the software to test for the presence (or absence) of +5 V to the solid state relays (Section 4.10).

3.4 Manual Control Unit Interface

PC0-PC7 of the relay PI/T and PC0-PC1 of the balance PI/T are used to detect the state of the MCU switches. The turntable direction switches and MCU detect lines are buffered through Schmitt triggers (74LS14) to minimise switch contact bounce. These lines are normally low (logic 0), and the software tests for a high (logic 1) to determine which switch has been activated (Section 4.5).

3.5 Test Section Detect Switch Interface

The active test section detection switches (Section 2.4) are connected to PA6 and PA7 of the relay PI/T. The software tests for a high (logic 1) on these lines to determine which test section is active (Section 4.6).

4. Microprocessor Control

The software consists of two sections:
- BPI control code to allow the master computer access to read and write data,
- and the turntable drive and control code.

The BPI control code is written in MC68000 assembler language and contains the memory management statements and all interrupt vector subroutines, which is the main interface between the Model Attitude Module and the master computer. Wind tunnel operators use software on the master computer [Ref. 1] to determine which turntables are to be driven and their respective target angles. The turntable control code is written in Ansi C and is called as a subroutine from the BPI control code.

The software is able to:
- Interface with the Bi-directional Parallel Interface (BPI) system.
- Drive up to five turntables in unison.
- Read up to five resolvers.
- Provide closed loop servo operation for the angular positioning of the turntables.
- Provide manual control of turntable movement.
- Enable software limit setting and control of turntable drive to prevent further movement beyond the limits.
- Provide direct resolver readings.
- Provide status information so the master computer can determine when the turntables have reached their desired target.
- Provide additional status information relating to resolver response, limits, manual control and relay power.
- Timeout from the main drive loop if a stall condition occurs.

A number of variables are used throughout the C code to store status information. Status variables are set to either TRUE (1) or FALSE (0) to signify hardware and software conditions. These variables are test routinely during all aspects of turntable operation:
- *channelok* - signifies if a resolver channel is functioning correctly,
- *anglevalid* - signifies if the angle returned from an encoder is valid,
- *angleset* - signifies if a channel's target angle has been set,
- *allowtoturn* - signifies if a turntable is to be moved,
- *drive* - a status variable that reflects direction of turntable movement.

4.1 Channel Initialisation

When the module is powered up or a system reset occurs, each channel's status variables are initialised to zero and each resolver is sequentially tested using the *readangle* routine (Section 4.3) to determine functionality. If the test determines that the

resolver channel is functioning correctly, that channel's *channelok* variable and the respective status variable bit is set to TRUE and logic HIGH (1) respectively (Section 4.9.2). The microprocessor will only monitor channels whose *channelok* variable is set to TRUE. If the resolver channel is not functioning correctly, that channel's *channelok* variable and status variable bit are set to FALSE and logic LOW (0) respectively.

The program then enters a wait loop which tests for changes in limits and target angles and acts on the move command from the master computer or responds to manual drive commands from the manual control units (Section 4.5).

4.2 BPI Interface

When the master computer addresses the Model Attitude Module an interrupt (IRQ5) is initiated on the VMEbus. The processor handles the interrupt by branching to a subroutine determined by the eight bit vector received. All addresses are in the form of 16 bit words, where an even address (e.g. 8660) is decoded as a FETCH (read) cycle, and an odd address (e.g. 8661) is decoded as a PASS (write) cycle. Specific technical information on the BPI interface is given in Reference 5.

The BPI address is formed by two eight bit bytes, the upper byte being the module specific address while the lower byte is a vector pointer. The vector pointers allow 255 individual routines to be selected.

The specific address allocated to the Model Attitude Module is '86XX', where the vector pointer XX in hexadecimal is selected from the range 00 to FF. Vectors 00 to 3F are for system use only while vectors 40 to 5F are assigned to user interrupts, which are used by VMEbus cards other than the relay drive card. The Model Attitude Module uses read/write vectors starting at vector 60 (8660) and continuing through to vector FF (86FF). The first sixteen vectors are used as general error/status and module identification vectors. The main movement trigger vector (8669), computer-controlled emergency stop vector (866B) and "read all resolver channels" vector (866D) are also included in this group.

Specific data for each turntable fetched from the module by the master computer includes:

- Resolver readings,
- Target angle settings (confirm target),
- Port limit angle settings,
- Starboard limit angle settings.

Data passed to the module by the master computer for each turntable includes:

- Target angle settings for each channel,
- Port limit angle settings,

- Starboard limit angle settings,
- and "allow turntable to move" command (Section 4.4).

Various vectors above vector D0 are used for module status. Appendix B contains detailed BPI vector information.

4.3 Resolver Reading

The *readangle* routine is used to read the resolver encoder for a particular channel. The port status register (PSR) in the PI/T attached to the encoder is read continually in a loop until either PSR6 goes high (signifying data ready) or the *watchdog* variable reaches the time-out count. If the time-out count is reached before PSR6 is asserted, the channel is considered to have failed its test, and that channel's *anglevalid* and *channelok* variables are set to FALSE and it's *resolver* status variable bit (Section 4.9.2) set to logic low. If PSR6 goes high before time-out occurs, the routine waits for it to return to low (signifying data stable), again employing another timer variable. If the second time-out count is reached, the channel is also considered to have failed the read test, and the *channelok, anglevalid* variables and *resolver* status bit set accordingly. If the resolver channel is functioning correctly, PSR6 goes low, and the 16 bit data is read from the PI/T data registers. The BCD data is converted to a decimal reading which is stored in the channel's *currentangle* variable. The *channelok* and *anglevalid* variables are then set to TRUE and the *resolver* status variable bit is set to logic high.

4.4 Turntable Movement and Positioning

A data write to BPI vector 8669 initiates the turntable movement procedure. The program first checks for MCU's (Section 4.5) and turns on the power to the relays (Section 4.10). For all channels whose *channelok, angleset* and *allowtoturn* variables are set to TRUE, their respective turntable select relays are activated and their resolvers read. The current angle is compared with the target angle and the required direction of the turntable determined. The *drive* status variable for each turntable is initialised to reflect their direction of travel i.e. to PORT or to STARBOARD. The respective turntable direction relays are activated, the channels' *movement* status bits (Section 4.9.1) are set to TRUE and the main drive loop is entered, which monitors the resolvers of each moving turntable.

If a turntable reaches a port or starboard limit, the turntable is stopped, the *limit hit* status bit (Section 4.9.2) is set to TRUE for that channel and the *movement* status bit reset to FALSE. If no limit is encountered, the resolver reading will reach the target angle value, where the drive relay is deactivated and the turntable is stopped. The channel's *drive* status variable is then reset to STOP and it's *moving* status bit is reset to FALSE.

The drive loop is continued until the status of all channels requiring movement has returned to STOP, then all turntable select relays are deactivated and the power to the relays is switched off. The program exits the drive loop and reverts back to the main wait loop.

4.5 Manual Control

During the main wait loop, the software tests for the presence of an MCU by testing PC0 and PC1 of the relay PI/T. If an MCU is plugged in, the corresponding *remote in* status bit (Section 4.9.3) is set to TRUE and the software tests the switches on the MCU during every execution of the wait loop. PC6 and PC7 of the relay PI/T (for test section 1) and PC0 and PC1 of the balance turntable PI/T (for test section 2) are tested to determine the position of the turntable select switch and the corresponding turntable select relay is activated (this relay is held on for as long as the MCU is plugged in, to prevent repetitive switching). A subsequent read of port C of the relay PI/T (PC2 and PC3 tested for test section 1, PC4 and PC5 tested for test section 2) determines if a turntable direction switch is pressed. If either the Port or Starboard switch is pressed, the appropriate turntable direction relay is activated. If the switch is released, the relay is deactivated. The software ignores the case of both switches being pressed, which could cause damage to the drive system.

If an MCU is connected, computer control of that test section is denied by the software, resetting the *allowtoturn* variables of both turntables in that test section to FALSE at the start of the turntable drive loop.

4.6 Active Test Section

At the start of the turntable drive loop the status of the test section detect switches is tested to determine the *active* test section. PA6 and PA7 of the relay PI/T are tested to determine whether test section 1 or test section 2 is active. If test section 1 is active the *allowtoturn* variables of both turntables in test section 2 are set to FALSE. Conversely, if test section 2 is active, the *allowtoturn* variables of test section 1 are set to FALSE. This ensures that the master computer can assert control only over the active test section, while the inactive test section can still be controlled with an MCU control.

4.7 Software Limits

Each turntable has two sets of variables associated with the setting of limits. *Portset* and *stbdset* are set to TRUE or FALSE indicating whether limits have been set by the master computer, and *portlimit* and *stbdlimit* hold the actual limit value. At the start of the program all *portset* and *stbdset* variables are set to FALSE. A data pass to any *set limit* vector also sets the corresponding *portset* or *starboardset* variable for that turntable from FALSE to TRUE.

During the turntable movement phase, if the *portset* or *stbdset* variable is TRUE, the resolver readings are continually compared with the limit values, i.e. if the turntable is moving to port, the resolver reading is checked against the port limit, while the starboard limit is checked for a turntable moving to starboard. If a resolver reading exceeds a limit, the turntable direction relay is deactivated and the turntable limit status (Section 4.9.2) changed accordingly.

Limits can be cleared by writing a value greater than 3600 to the corresponding limit vector. This sets the relevant *portset* or *stbdset* variable to FALSE.

4.8 Resolver Reading Display

The resolver readings for each turntable are available to be read by the master computer at any time. After the channel initialisation process the resolver readings for every channel are taken and stored in their respective BPI vector addresses. During the turntable movement phase the resolver reading for all moving channels are constantly updated. The master computer accesses these readings by addressing the appropriate BPI vectors.

4.9 Status Information

Three BPI vectors are utilised to inform the master computer of the various status conditions of the module and turntables. A fetch (read) of the BPI addresses 86D0, 86D2 and 86D4 is required to access status information. These vectors are described in the following sections:

4.9.1 Turntable Movement Status

The BPI vector 86D0 is defined as the movement status vector. Individual bits are used as status flags. If a bit is set to logic 1 (TRUE) the turntable is currently moving, a logic 0 (FALSE) means the turntable is stationary. A test of these bit patterns, which are shown in Table 1, will determine if a turntable is moving or not.

If several turntables are moving simultaneously, their respective bits will be set TRUE to reflect their status. For example, a fetch of address 86D0 could yield the results shown in Table 2. If all bits are FALSE then all turntables are stationary. This results in the hex word 0000 being read.

4.9.2 Resolver and Turntable Limit Status

The BPI vector 86D2 is defined as the resolver and turntable limit status vector. The possible bit patterns are shown in Table 3.

Table 1: Turntable Movement Status Bit Patterns

Address	Bit Pattern	Hex	Status
86D0	0000000000000001	0001	Test Section 1 upper turntable moving
	0000000000000010	0002	Test Section 1 lower turntable moving
	0000000000000100	0004	Test Section 2 upper turntable moving
	0000000000001000	0008	Test Section 2 lower turntable moving
	0000000000010000	0010	Balance turntable moving
	0000000100000000	0100	Test Section 1 upper turntable stalled
	0000001000000000	0200	Test Section 1 lower turntable stalled
	0000010000000000	0400	Test Section 2 upper turntable stalled
	0000100000000000	0800	Test Section 2 lower turntable stalled
	0001000000000000	1000	Balance turntable stalled

Table 2: Example of Turntable Movement Status Bit Test

Address	Bit Pattern	Hex	Status
86D0	0000000000000011	0003	Test Section 1 upper and lower turntables both moving.
Or			
86D0	0000000000011100	001C	Test Section 2 upper and lower turntables and Balance moving.

Table 3: Resolver and Turntable Limit Status Bit Patterns

Address	Bit Pattern	Hex	Status
86D2	0000000000000001	0001	Test Section 1 upper resolver functioning OK
	0000000000000010	0002	Test Section 1 lower resolver functioning OK
	0000000000000100	0004	Test Section 2 upper resolver functioning OK
	0000000000001000	0008	Test Section 2 lower resolver functioning OK
	0000000000010000	0010	Balance resolver functioning OK
	0000000000100000	0020	Test Section 1 upper turntable exceeded port limit
	0000000001000000	0040	Test Section 1 lower turntable exceeded port limit
	0000000010000000	0080	Test Section 2 upper turntable exceeded port limit
	0000000100000000	0100	Test Section 2 lower turntable exceeded port limit
	0000001000000000	0200	Balance exceeded port limit
	0000010000000000	0400	Test Section 1 upper turntable exceeded starboard limit
	0000100000000000	0800	Test Section 1 lower turntable exceeded starboard limit
	0001000000000000	1000	Test Section 2 upper turntable exceeded starboard limit
	0010000000000000	2000	Test Section 2 lower turntable exceeded starboard limit
	0100000000000000	4000	Balance exceeded starboard limit

4.9.3 Manual Control and Power Status

The BPI vector 86D4 is defined as the manual control and power status vector. The possible bit patterns are shown in Table 4.

Table 4: Manual Control and Power Status Bit Patterns

Address	Bit Pattern	Hex	Status
86D4	0000000000000001	0001	Manual Control Unit 1 plugged in
	0000000000000010	0002	Manual Control Unit 2 plugged in
	0000000000000100	0004	Emergency Stop Switch activated

The status variables relating to vectors 86D2 and 86D4 are automatically cleared after a data fetch (read) of these vectors. The turntable movement status variable (86D0) is cleared at the completion of the main drive loop (clearing any *turntable stalled* bits that are set to TRUE) to ensure the movement status is not disrupted.

4.10 Relay Power Control

The voltage regulator that supplies power to the turntable relays (Section 3.3) is controlled by PA4 of the relay PI/T. A logic 1 turns the regulator on, while a logic 0 turns it off. This allows for software control of relay power, which is only turned on at the start of the turntable movement phase or when either of the MCU's (Section 4.5) are connected.

The status of the Emergency Stop switch is continuously monitored throughout the turntable movement phase. If it is found to be open circuit (i.e. has been pressed) the status of all moving turntables is reset to STOP to complete the drive loop and the Emergency Stop bit of the power status vector is set to TRUE (Section 4.9.3).

4.11 Drive Loop Timeout

A timeout feature is included in the main turntable drive loop, and is implemented by incrementing a counter variable on each pass through the drive loop. A timeout will occur when a functioning channel is commanded to move but stalls during the movement phase or does not move at all due to mechanical or electronic component failure. If a channel's *counter* variable reaches the *STALL_TIME* value (which will occur after approximately 2 seconds), and the resolver reading has not changed in that time, that channel's drive relay is deactivated and it's drive status reset to STOP. The *stalled* status bit is set to TRUE to inform the master computer of this condition.

5. Master Computer Drive Procedure

5.1 Overview

In order to drive a turntable to a predetermined angle, it is necessary to complete three tasks:

1. Determine the target angle.
2. Allow the turntable to turn.
3. Trigger turntable movement.

The resolver and encoder used to determine turntable angle outputs a reading from 0° to 360° with a resolution of 0.1°. However, the BPI passes only integer numbers, therefore the decimal point is not included in angles transmitted to and from the module, which gives a range of values from 0 to 3600. For example, an angle of 90° will be read as 900, and an angle of 320° will be read as 3200.

By convention, the wind tunnel operators have set up the turntables so that 0° is defined as being directly into the wind when the long pylon support slot in the turntable is positioned perpendicular to the wind direction (Figure 9). Each resolver is calibrated to give a reading of 0° to match this convention. The terms *port* and *starboard* are in reference to the test section. When looking directly into the wind, a rotation to port will be to the left, and a rotation to starboard will be to the right. This applies to all turntables. The following figures depicting turntable movement show the turntables as viewed from outside the test section looking downwards.

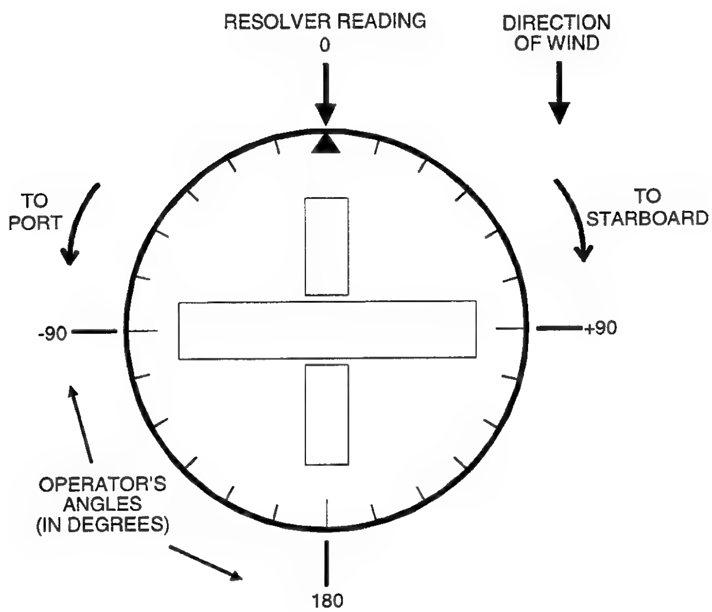

Figure 9: Initial Resolver Reading Setup

The reading for each **lower** turntable <u>**increases**</u> from 0° as the turntable moves in the starboard direction (0°, 10°, 20°, 30° etc.) while the reading for each **upper** turntable <u>**decreases**</u> from 0° (360°) as the turntable moves in the starboard direction (0°, 350°, 340°, 330° etc.).

The module software expects the target or limit angle data being sent to it to be in the range 0 to 3600, whereas the operator will be dealing with angles in the range 0° to ±180°. It is therefore necessary for the master computer to convert the data that are sent to and received from the module into a form the operator expects [Ref. 1].

5.2 Setting a Target Angle for the Lower Turntables

Data conversion for the lower turntables can be performed using the following two equations:

a) for a target angle in the range 0° to +180°:

$$\text{data sent} = \text{target} \times 10 \tag{1}$$

where **target** is a positive number.

b) for a target angle in the range 0° to -180°:

$$\text{data sent} = (360 + \text{target}) \times 10 \tag{2}$$

where **target** is a negative number.

For example, if the operator wishes to rotate the **lower** turntable in test section 1 to an angle of +45° (from 0°), the following steps are performed:

1. The data to be sent to the module is calculated using Equation (1):

$$\text{data sent} = 45 \times 10 = \mathbf{450}$$

A data pass to BPI address 8693 with data 450 is executed to set the target angle.

2. A data pass to BPI address 86A3 (with no specific data) is executed to enable control of the test section 1 lower turntable.
3.
4. A data pass to BPI address 8669 (with no specific data) is executed to trigger turntable movement.
5.

The result is a movement to starboard as shown in Figure 10.

As another example, if the operator wishes to rotate the **lower** turntable in test section 1 to -60°, the data to be sent to address 8693 is calculated using Equation (2):

$$\text{data sent} = (360 + (-60)) \times 10 = \mathbf{3000}$$

After subsequent data passes to addresses 86A3 and 8669, the result would be a movement to port as shown in Figure 11.

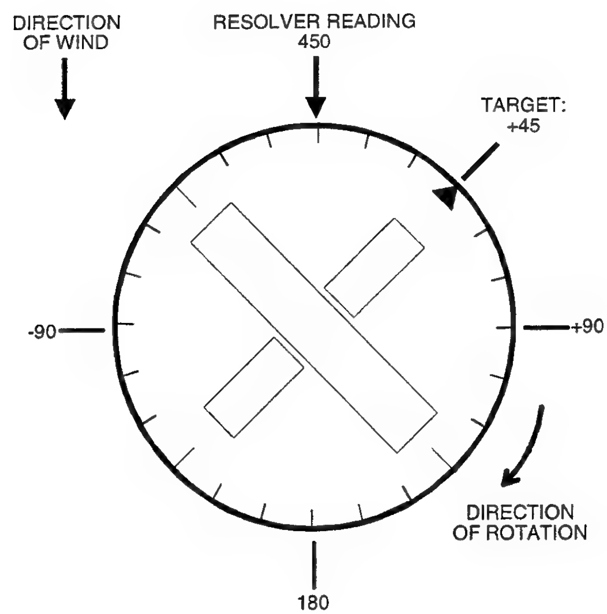

Figure 10: Lower Turntable Movement to +45°

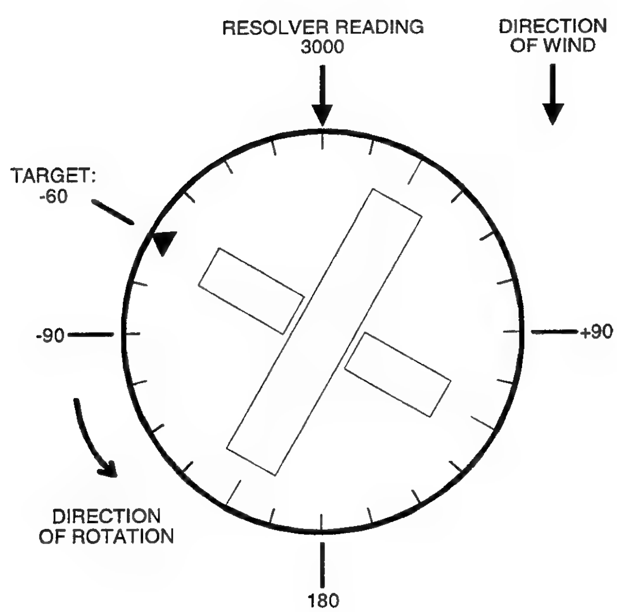

Figure 11: Lower Turntable Movement to -60°

5.3 Setting a Target Angle for the Upper Turntables

Target angles for the upper turntables can be calculated using the following equations:

a) for a target angle in the range 0° to +180°:

$$\text{data sent} = (360 - \text{target}) \times 10 \tag{3}$$

where **target** is a positive number.

b) for a target angle in the range 0° to -180°:

$$\text{data sent} = -(\text{target}) \times 10 \tag{4}$$

where **target** is a negative number.

For example, if the operator wishes to rotate the **upper** turntable in test section 1 to an angle of +45° (from 0°), the following steps are performed:

1. The data to be sent to the module is calculated using Equation (3):

$$\text{data sent} = (360 - 45) \times 10 = \mathbf{3150}$$

A data pass to BPI address 8691 with data 3150 is executed to set the target angle.

2. A data pass to BPI address 86A1 (with no specific data) is executed to enable control of the test section 1 upper turntable.

3. A data pass to BPI address 8669 (with no specific data) is executed to trigger turntable movement.

The result is a movement to starboard as shown in Figure 12.

As another example, if the operator wishes to rotate the upper turntable in test section 1 to -60°, the data to be sent to address 8691 is calculated using Equation (4):

$$\text{data sent} = -(-60) \times 10 = \mathbf{600}$$

After data passes to addresses 86A1 and 8669, the result would be a movement to port as shown in Figure 13.

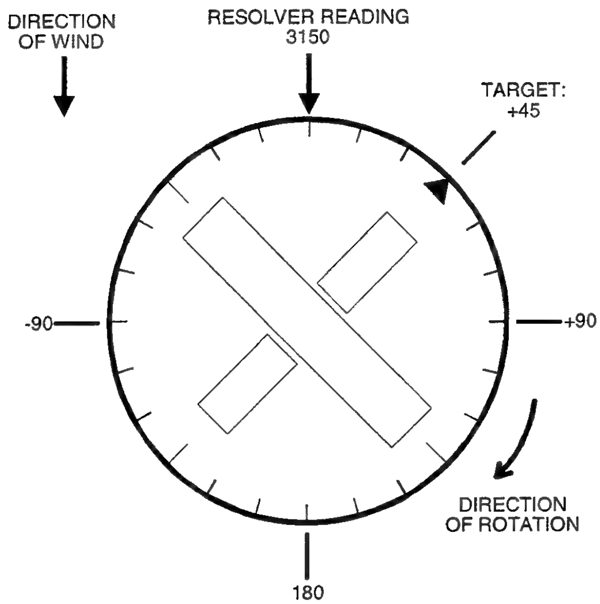

Figure 12: Upper Turntable Movement to +45°

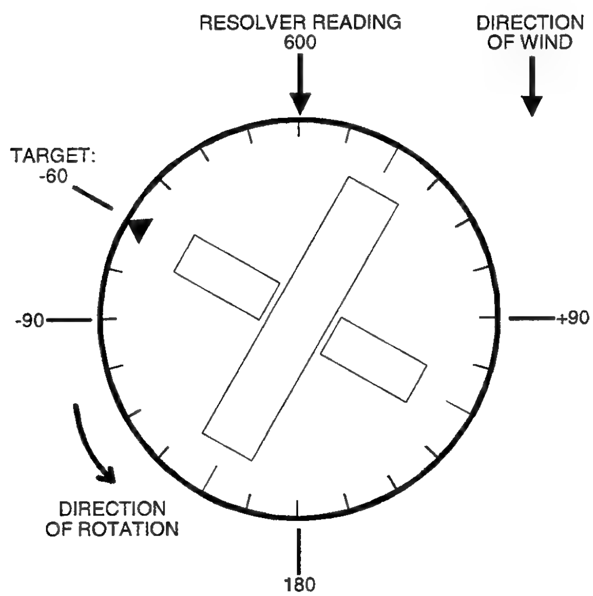

Figure 13: Upper Turntable Movement to -60°

5.4 Setting a Target Angle for Upper and Lower Turntables to Move Together

If the operator wishes to move the upper and lower turntables in unison the target angles must be calculated using Equations (1) or (2) for the lower turntable and Equations (3) or (4) for the upper turntable. If both turntables are required to move in the same direction to the same target angle, Equations (1) and (3) must be used together for a positive target angle, and Equations (2) and (4) for a negative target angle.

For example, if a target angle of +30° is required for both turntables, the following steps must be performed:

1. The target angle for the lower turntable is calculated using Equation (1):

$$\text{data sent} = 30 \times 10 = \mathbf{300}$$

2. The target angle for the upper turntable is calculated using Equation (3):

$$\text{data sent} = (360 - 30) \times 10 = \mathbf{3300}$$

3. The target angles are set by a data pass to BPI address 8693 with data 300 for the lower turntable and a data pass to BPI address 8691 with data 3300 for the upper turntable.

4. Data passes to BPI addresses 86A1 and 86A3 (both with no specific data) are executed to enable movement of both upper and lower turntables in test section 1.

5. A data pass to BPI address 8669 (with no specific data) is executed to trigger turntable movement.

The result is a movement to starboard of both turntables in unison as shown in Figure 14 and Figure 15.

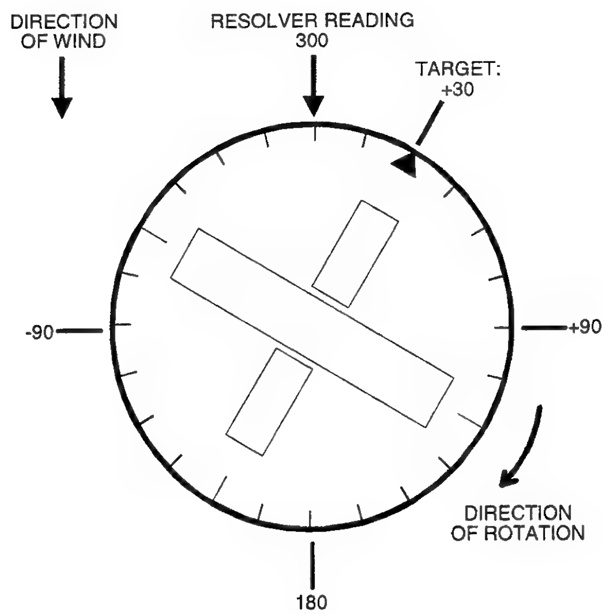

Figure 14: Lower Turntable Movement to +30°

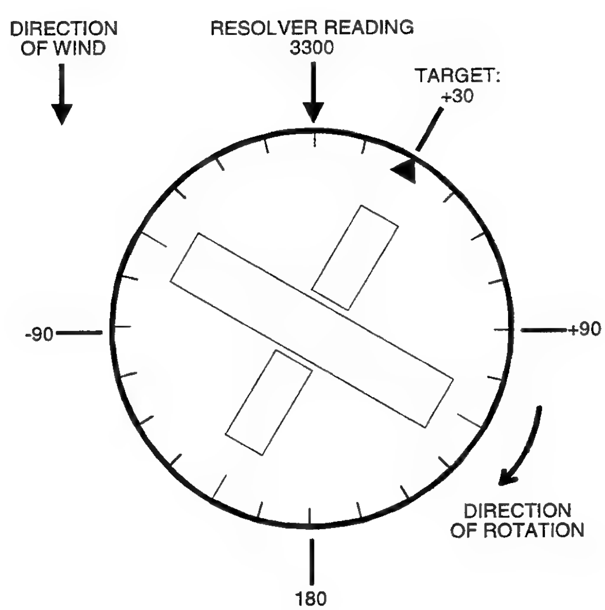

Figure 15: Upper Turntable Movement to +30°

6. Software Development Procedure

6.1 Module Configuration for Software Development

Additional equipment is required for software development, and includes the following hardware:

- 1 IBM compatible personal computer with a PC BPI card.
- 1 CK600 video display unit.
- 1 serial interface circuit (placed between the PC and the module's ACIA card to protect the serial port of the PC).

The Model Attitude Module consists of the following cards:

- Slot 1: MC68000 CPU card.
- Slot 2: Memory card with eight 6264 static RAM chips (base address switchable from 10000H to 00000H).
- Slot 3: Memory card with two 2732 EPROMs containing monitor program MONITOR v11.1 and four 6116 static RAM chips (base address switchable from 00000H to 10000H).
- Slot 4: BPI card.
- Slot 5: Asynchronous communication card (ACIA).
- Slot 6: Relay drive card.
- Slot 8: PI/T card.
- Slot 9: PI/T card.
- Slot 10: PI/T card.

6.2 Development Version of Software

The compiler software used for compiling and testing the Model Attitude Module code is the **HI-TECH** C to MC68000 cross compiler, and is executed from the **C:\HITECH** directory on the Dolch 486 personal computer.

The turntable drive and monitoring code **(MODELATC.C)** is written in Ansi C and is executed from within the BPI control code **(MODELATA.AS), which is** written in MC68000 assembler language. After either file has been modified, it is necessary to recompile the complete code by running the batch file **MODELATT.BAT**. This executes the MAKE utility which processes a script file called **MODELATT.MAK**. This file contains the commands to compile and link all relevant library and header files with the assembler and C code and create the file **MODELATT.HEX, which contains the executable machine code** in Motorola S Hex format.

Before MODELATT.HEX can be downloaded to the module, the serial port on the personal computer (COM1) must be configured to 4800 baud to match the baud rate set in the ACIA card by the monitor program. This is done by executing the MS-DOS MODE command in the following manner:

MODE COM1:4800,n,8,1 <enter>

The cable from the ACIA card is plugged into the COM1 port and the memory select switch is in the *MON* (monitor) position. The monitor prompt *"Hi!"* will appear on the CK600 display unit connected to the ACIA card.

The DOS command **CTTY** is used to change the terminal device controlling the personal computer. At the DOS prompt on the personal computer type:

CTTY COM1 <enter>

to allow the personal computer to be controlled by commands via the serial port. Then on the CK600 terminal type:

H <enter>

to gain access to the personal computer through the monitor's Host command. The DOS prompt should appear on the terminal screen. MODELATT.HEX is then downloaded by running **D.BAT**, a DOS batch file which runs the file dump utility CDMP.EXE in the C:\HITECH directory. On the CK600 keyboard type:

D MODELATT <enter>

The message *"starting dump modelatt.o"* will appear on the screen. At the completion of the file download the *"Hi!"* prompt reappears on the terminal screen. Control is restored to the personal computer by typing:

H <enter>

Then on the terminal type type:

CTTY CON <enter>

to restore control to the personal computer keyboard. Typing the key combination Ctrl-C on the terminal then restores the *"Hi!"* monitor prompt.

After system reset the MC68000 microprocessor executes code from address 00000H (Hex). The monitor code already exists at this address so the development code is compiled to download to address 10000H in RAM but is linked to start execution at 00000H. The program is executed by pressing and holding the RESET button on the CPU card and switching the memory select switch to the 'RAM' (RAM memory) position. This changes the base address of the RAM memory card from 10000H to 00000H, and the base address of the card containing the monitor EPROMs from 00000H to 10000H. Releasing the RESET button causes the downloaded program to execute.

Development diagnostic messages appear on the CK600 terminal screen during execution of the Model Attitude Module software. BPI read and write functions are carried out on the personal computer using the **PCBPI.EXE** program.

6.3 Final (EPROM) Version of Software

The EPROM version of the Model Attitude Module code is edited and compiled in a similar manner to the development version, although different files are used. The final version of Model Attitude Module specific code is called **MODC.C** and is called from **MODA.AS**. These two files are compiled using the batch file **MOD.BAT** which executes the MAKE utility and processes **MOD_PROM.MAK**. The resultant .HEX file is **MOD.HEX** which is programmed into EPROMs. No diagnostic messages are used in the final version so the ACIA card is not required. The final hardware configuration is described in Section 2.1.

To program the EPROMs, enter the **C:\UNI-PROG** directory on the personal computer with the Hi-Lo Systems ALL-03A Universal Programmer connected to it. Execute **EPP512.EXE** to program 2764 EPROMs. Ensure that the correct EPROM manufacturer and type are selected by using ***M*** (manufacturer) and ***T*** (type) in the Main Menu), and load the hex file **MOD.HEX** into the programmer buffer by using option 2 in the Main Menu. Select ***M*** to load Motorola S HEX format and accept the default file start address (00000000). Unused bytes can be selected as "don't care".

Four 2764 EPROMs are required for the Model Attitude Module program. To program the two EPROMs in the address range 0000 to 3FFF select **Z** in the Main Menu to set the Target Zone, and set the buffer start address to 0000, the buffer end address to 3FFF and the device start address to 0000. Return to the Main Menu (by pressing the Escape or Enter keys) and select ***P*** to program the EPROMs. Type ***O*** to program the odd (upper) bytes then ***E*** to program the even (lower) bytes. For address range 4000 to 7FFF, reset the Target Zone from the Main Menu again to give a buffer start address of 4000, a buffer end address of 7FFF and device start address of 0000. Select ***P*** to program the remaining two EPROMs (odd and even) as for the first two. Figure shows the positioning for odd and even EPROMs on the memory card.

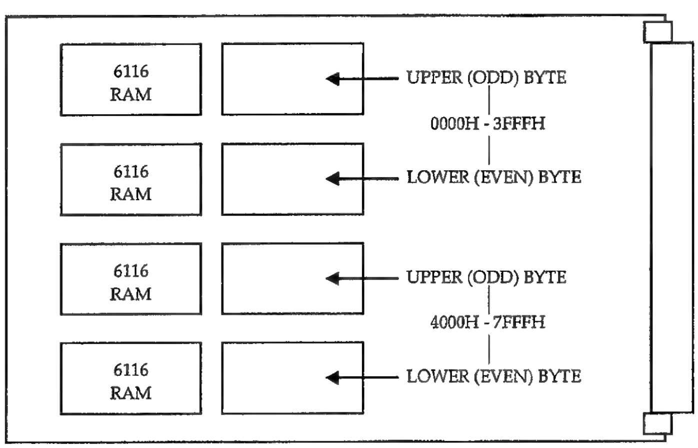

Figure 16: Memory Card EPROM Configuration

7. Conclusion

The Model Attitude Module hardware and software have both undergone extensive evaluation and have found to be operating reliably and within specification. The turntables can be driven independently and synchronously with control from either the microVax system or the manual control units. At the time of writing the under-section mechanical balance turntable could not be tested as it was not in place. There is provision for the future fit of a sidewall turntable that can be controlled by this module.

8. Acknowledgments

The author wishes to acknowledge the assistance of Scott Dutton and Fred Bird for providing a significant part of the initial software and hardware framework. The author would also like to thank Yoel Link for his assistance and suggestions during the development and testing of the module software.

9. References

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Appendix A: Schematic Details

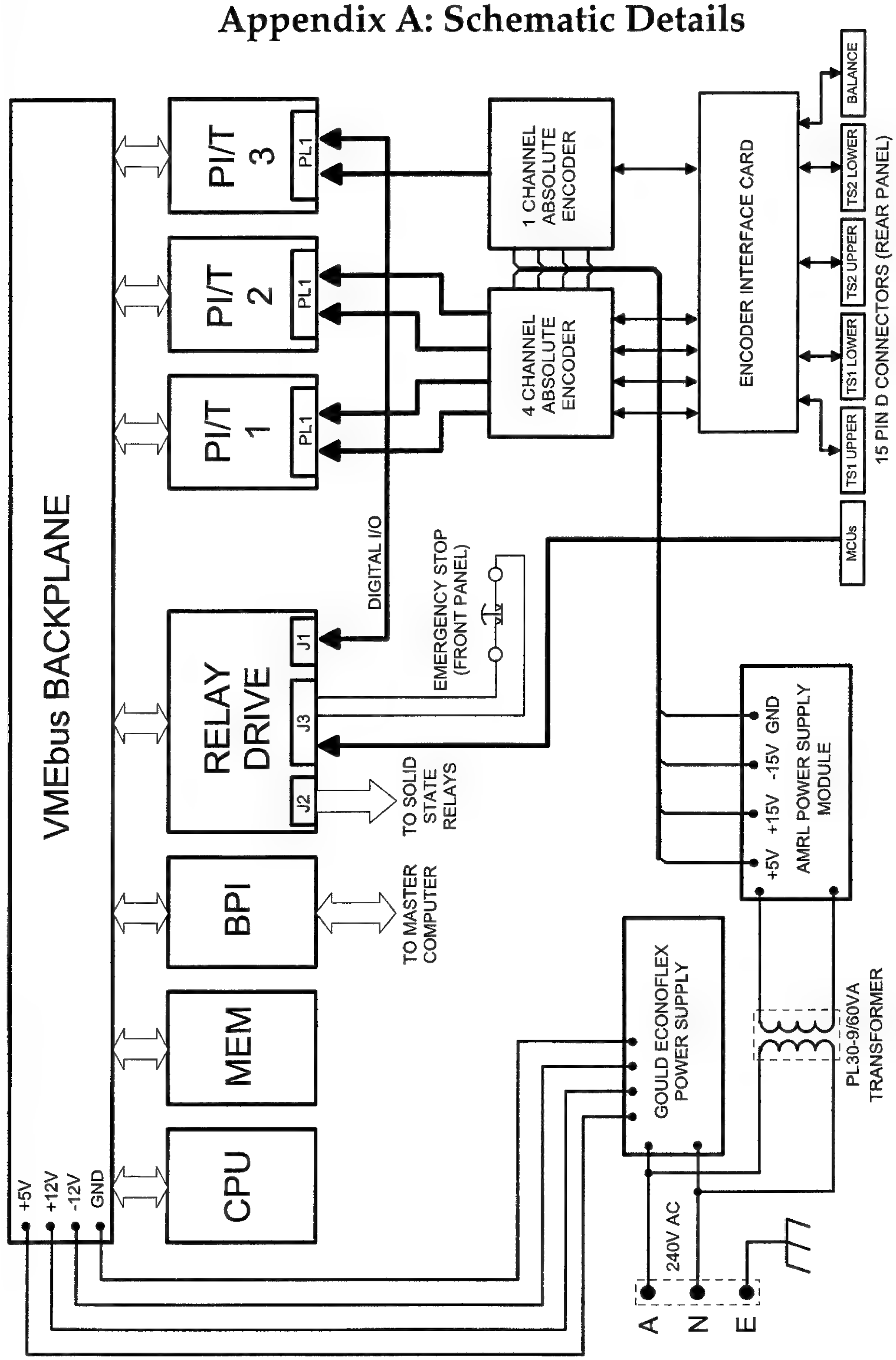

Figure A1: Model Attitude Module Block Diagram

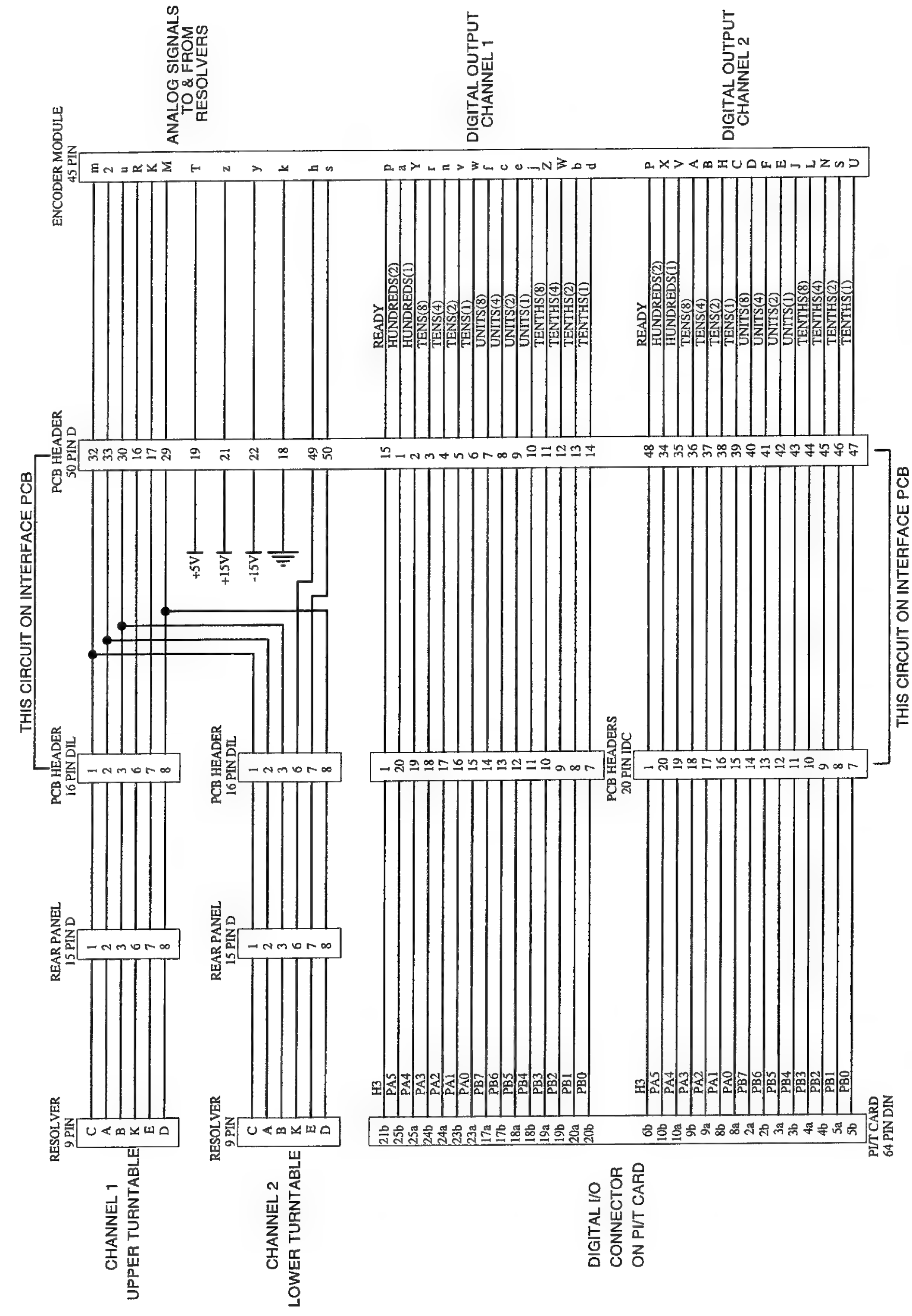

Figure A2: Resolver-Encoder Interface Circuit Diagram

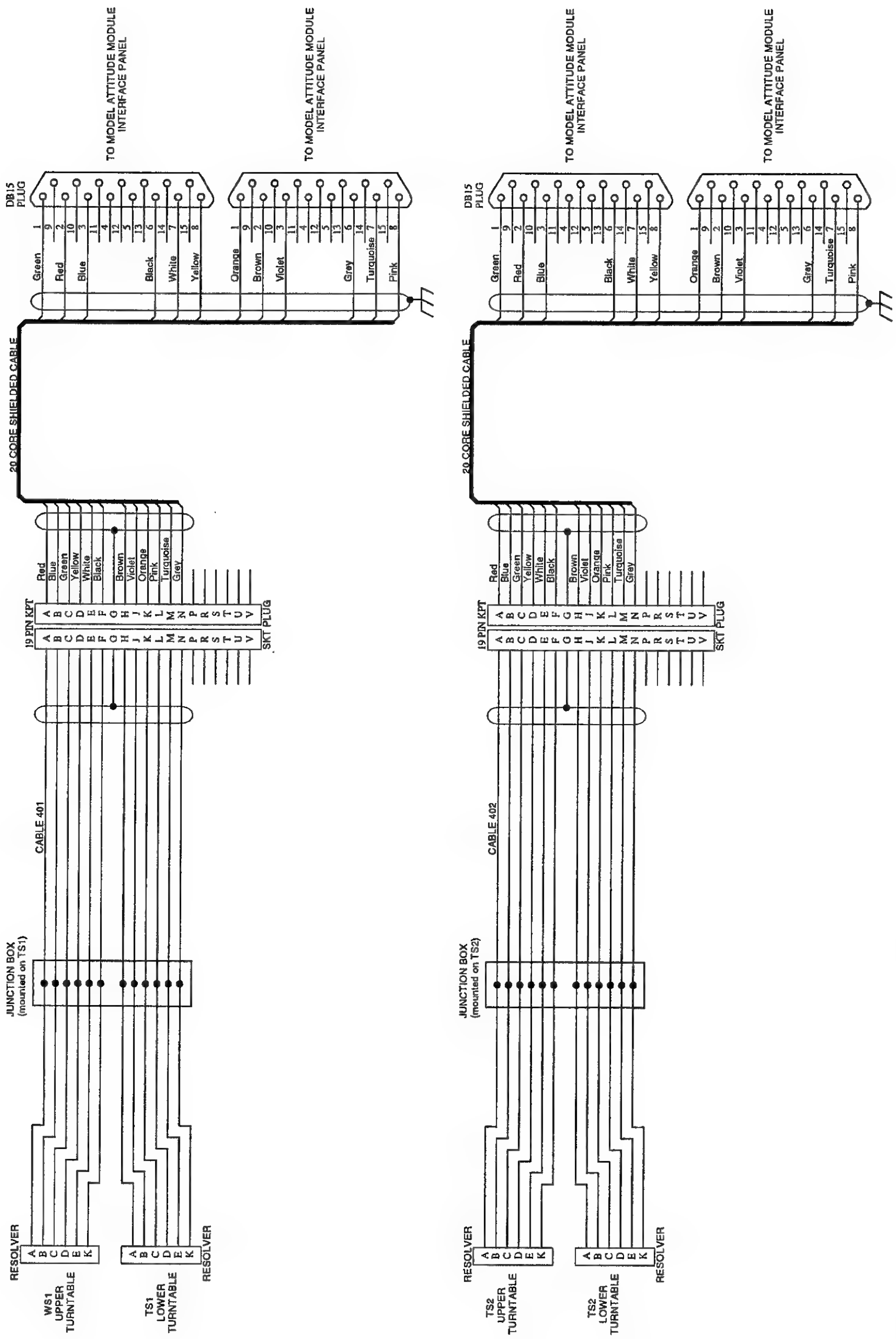

Figure A3: Resolver Cable Circuit Diagram

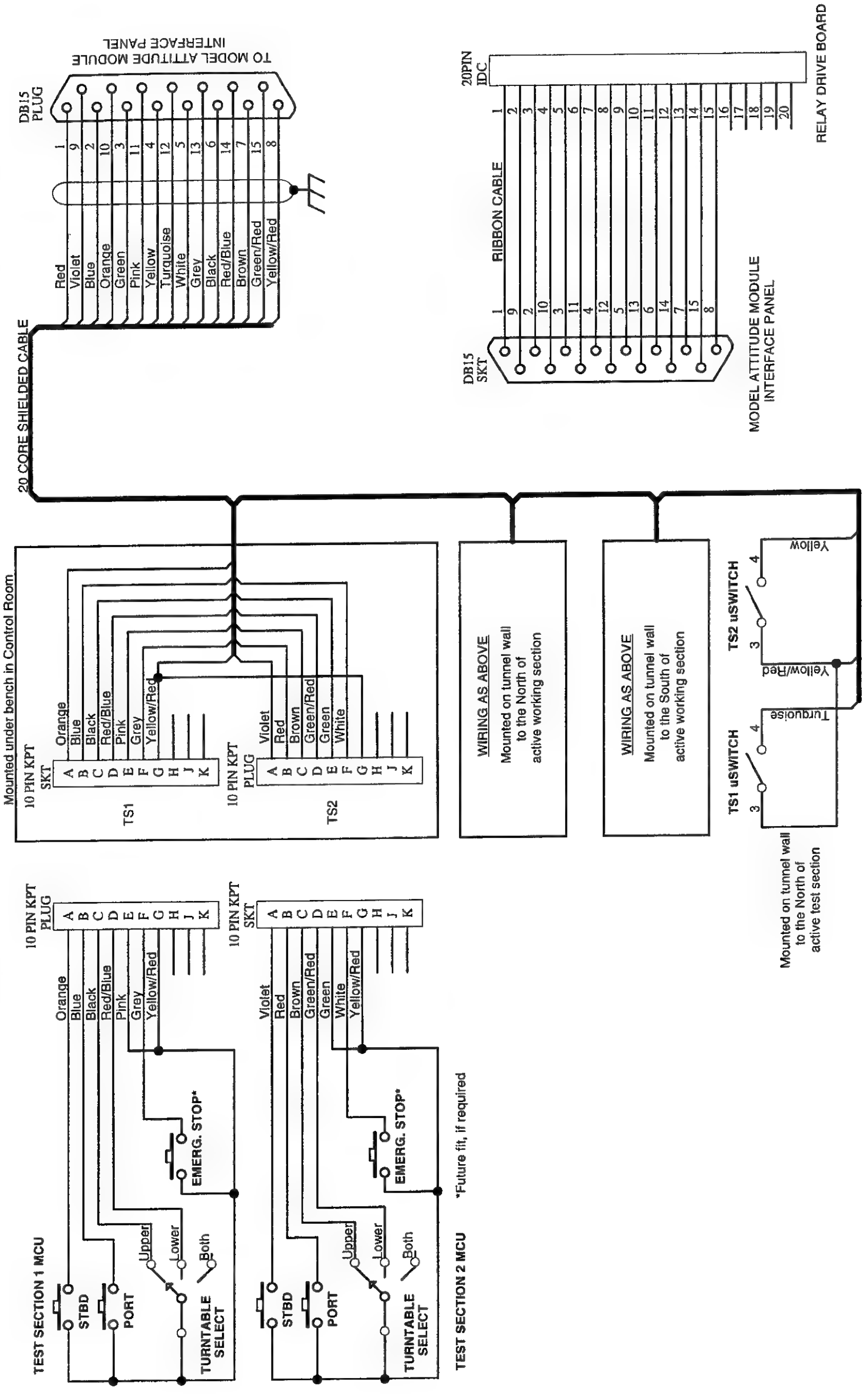

Figure A4: Manual Control Unit (MCU) Circuit Diagram

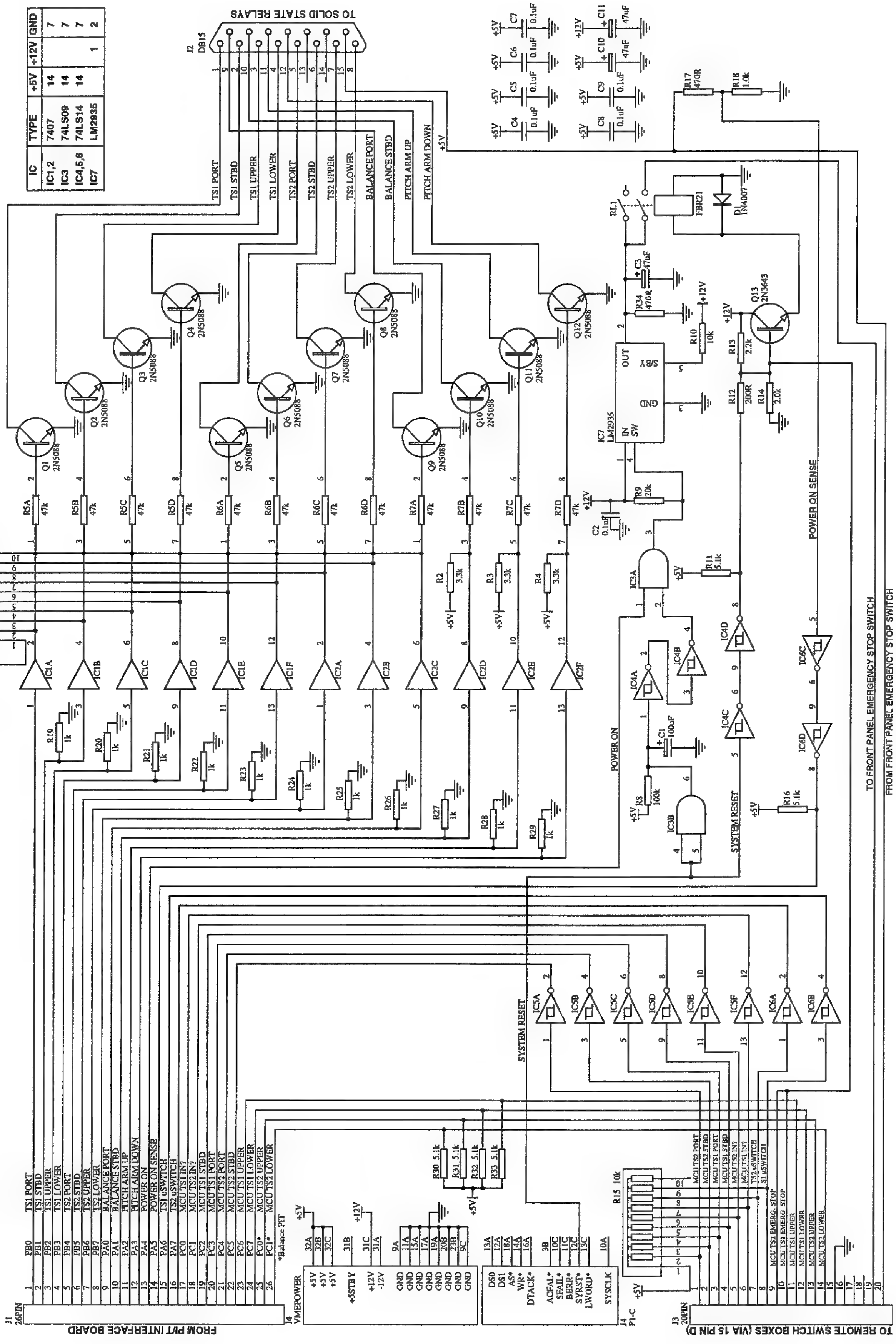

Figure A5: Relay Drive Card Circuit Diagram

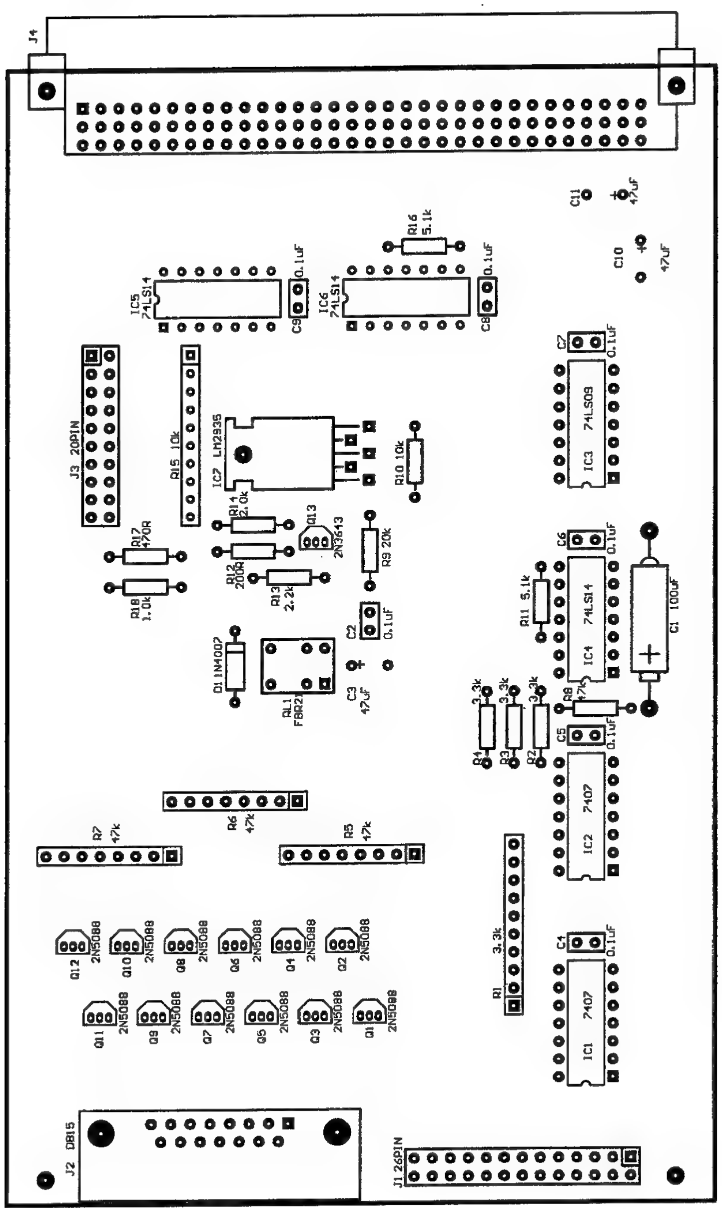

Figure A6: Relay Drive Card Component Overlay

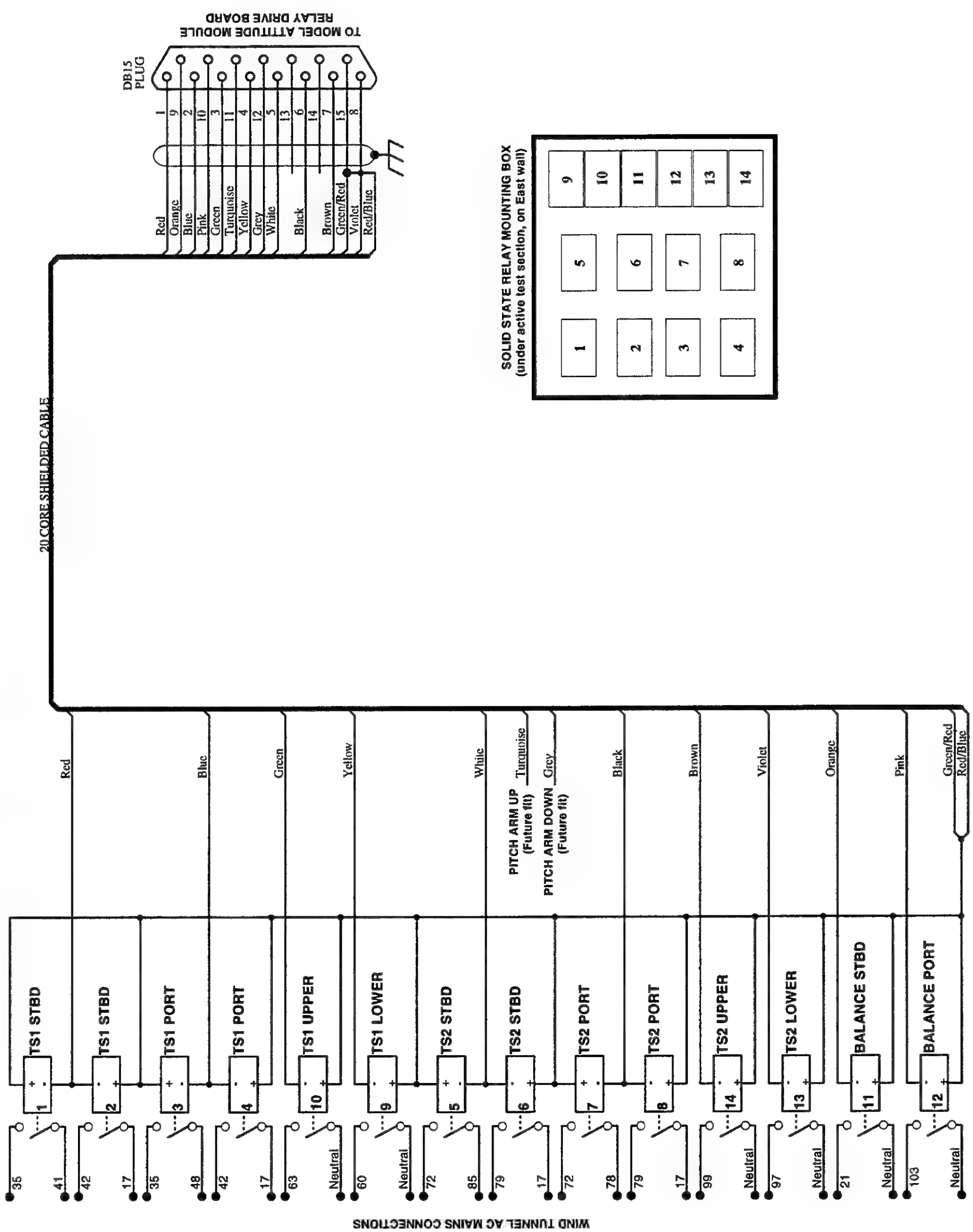

Figure A7: Solid State Relay Interface Circuit Diagram

Appendix B: BPI Vector Assignments

VECTOR	ADDRESS	LABEL	USE
vec96	8660	strin1	string1 - error codes (codes, NULL)
vec98	8662	strin2	string2 - module identification string
vec99	8663	trig	master trigger (not used in this module)
vec101	8665	clster	clear error/status buffers
vec103	8667	clerfg	clear error and flag bits
vec105	8669	travel	trigger turntable movement
vec107	866B	stopnow	stop all motors
vec109	866D	readall	read all resolver channels
vec112	8670	rdat1	read port limit test section 1 upper
vec113	8671	wdat1	set port limit test section 1 upper
vec114	8672	rdat2	read port limit test section 1 lower
vec115	8673	wdat2	set port limit test section 1 lower
vec116	8674	rdat3	read port limit test section 2 upper
vec117	8675	wdat3	set port limit test section 2 upper
vec118	8676	rdat4	read port limit test section 2 lower
vec119	8677	wdat4	set port limit test section 2 lower
vec120	8678	rdat5	read port limit Balance
vec121	8679	wdat5	set port limit Balance
vec128	8680	rdat9	read starboard limit test section 1 upper
vec129	8681	wdat9	set starboard limit test section 1 upper
vec130	8682	rdat10	read starboard limit test section 1 lower
vec131	8683	wdat10	set starboard limit test section 1 lower
vec132	8684	rdat11	read starboard limit test section 2 upper
vec133	8685	wdat11	set starboard limit test section 2 upper
vec134	8686	rdat12	read starboard limit test section 2 lower
vec135	8687	wdat12	set starboard limit test section 2 lower
vec136	8688	rdat13	read starboard limit Balance
vec137	8689	wdat13	set starboard limit Balance
vec144	8690	rdat17	read target angle test section 1 upper
vec145	8691	wdat17	set target angle test section 1 upper
vec146	8692	rdat18	read target angle test section 1 lower
vec147	8693	wdat18	set target angle test section 1 lower
vec148	8694	rdat19	read target angle test section 2 upper
vec149	8695	wdat19	set target angle test section 2 upper
vec150	8696	rdat20	read target angle test section 2 lower
vec151	8697	wdat20	set target angle test section 2 lower
vec152	8698	rdat21	read target angle Balance
vec153	8699	wdat21	set target angle Balance
vec161	86A1	wdat25	allow test section 1 upper to turn
vec163	86A3	wdat26	allow test section 1 lower to turn
vec165	86A5	wdat27	allow test section 2 upper to turn
vec167	86A7	wdat28	allow test section 2 lower to turn
vec169	86A9	wdat29	allow Balance to turn
vec171	86AB	wdat30	Don't allow any turntables to turn

VECTOR	ADDRESS	LABEL	USE
vec177	86B1	wdat33	synchronise test section 1 Upper and Lower
vec179	86B3	wdat34	synchronise test section 2 Upper and Lower
vec181	86B5	wdat35	synchronise test section 1 Upper, Lower and Balance
vec183	86B7	wdat36	synchronise test section 2 Upper, Lower and Balance
vec185	86B9	wdat37	synchronise test section 1 Lower and Balance
vec187	86BB	wdat38	synchronise test section 2 Lower and Balance
vec189	86BD	wdat39	no synchronisation
vec192	86C0	rdat41	read current angle test section 1 Upper
vec194	86C2	rdat42	read current angle test section 1 Lower
vec196	86C4	rdat43	read current angle test section 2 Upper
vec198	86C6	rdat44	read current angle test section 2 Lower
vec200	86C8	rdat45	read current angle Balance
vec202	86D0	rdat46	read turntable status
vec204	86D2	rdat47	read channel and limits status
vec206	86D4	rdat48	read MCU and power status

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19. ABSTRACT

The Low Speed Wind Tunnel at the Aeronautical and Maritime Research Laboratory (AMRL) has, as part of its system, two interchangeable chambers, known as "test sections" where models to be tested are mounted. One of the requirements of a recent upgrade to the Low Speed Wind Tunnel control and data acquisition system was the ability to precisely position the turntables using computer control. This report describes the electronic hardware and software developed to enable computer control of the turntables by wind tunnel personnel.

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